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CR-170937



Preliminary Studies of Solar Advance Observatory  
and  
Solar Beacon Facility

Final Report for the contract NAS8-34573

Submitted To

Marshall Space Flight Center  
National Aeronautics and Space Administration

Prepared by:

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### Acknowledgement

The principal investigator wishes to express his sincere thanks to Mr. W. T. Roberts of the Program Development Office, Dr. E. Hildner and Dr. R. L. Moore, Solar Science Branch, Space Science Laboratory at MSFC for their guidance to conduct this study. Without their enthusiastic active participation, I don't believe that it would have brought the present progress.

### Summary

The scientific working group for both Advance Solar Observatory (ASO) and Solar Beacon Facility (SBF) were organized to study the scientific needs, requirements and technology for these two facilities. There were five meetings for ASO and three meetings for SBF. During the course of study, both chairmen of the scientific working groups: Dr. A. B. C. Walker (Stanford University) and Dr. J. M. Beckers (University of Arizona) visited MSFC/NASA many times to discuss the engineering design and state-of-the-art of technology with members of the engineering team.

## I. Introduction

The availability of the Space Transportation Systems (STS) and Space-lab in the 1980s will greatly enhance the capability for space science and application. These new systems will facilitate the launch, retrieval, refurbishment, and reflight of scientific payloads. These payloads will be in the forms of traditional free-flying spacecraft, spacelab (STS - attached) payloads, and future space science platform/station. This new retrieval capability, coupled with the large weight-carrying and power capabilities of the STS, makes possible the evolutionary development of large and complex instruments and facilities. The assembly of complementary groups of instruments that may be reconfigured from flight to flight to address different scientific problems will also be possible. In order to take advantage of these new capabilities for future space solar astronomy programs and to ensure the participation of the scientific community in determining these future space solar astronomy programs, Marshall Space Flight Center has requested the University of Alabama in Huntsville (UAH) to organize scientific study groups to investigate the scientific justifications, requirements and benefits to develop the Advance Solar Observatory (ASO) and Solar Beacon Facility (SBF).

To achieve these goals, UAH invited interested scientists from universities, private industry and government agencies to form two scientific study groups for ASO and SBF respectively to conduct these studies. In the next sections, we shall describe the progress of these two studies.

## II. Advance Solar Observatory

The Advanced Solar Observatory (ASO) is a proposed long duration space observatory which would be placed on a space shuttle serviced space station or space platform. The ASO will consist of four major instrument groupings

or facilities:

1. A High Resolution Solar Telescope Cluster. This facility will carry out high resolution studies of the sun's interior dynamics by observing the global oscillations of the sun, the solar photosphere, chromosphere and low corona at optical, ultraviolet, extreme ultraviolet, XUV and soft x-ray wavelengths.
2. A Pinhole/Occulter Facility. This facility is designed for the study at high angular resolution of the outer corona and the solar wind at optical, ultraviolet and extreme ultraviolet wavelengths, and of transient phenomena such as flares at hard x-ray energies.
3. A Solar High Energy Facility. This facility is designed for spectroscopic observations of transient phenomena at hard x-ray and gamma ray energies, and for the study of solar neutrons.
4. A Solar Low Frequency Radio Facility. This facility is designed for the study of particle acceleration and propagation in the corona and inner heliosphere.

The scientific problems which the ASO could be addressed may be outlined as follows:

- To provide direct empirical tests of models of the internal structure and dynamics of the sun
- To investigate the central role played by magnetic reconnection and particle acceleration in solar flares, and in other explosive phenomena in astrophysics.
- To identify and study the mechanisms responsible for the acceleration, structure, and composition of solar wind.

- To identify and study the mechanisms responsible for the generation of the solar magnetic field, and the operation of the solar activity cycle.
- To identify and study the causes of long-term variations in the solar magnetic and activity cycle.
- To investigate the mechanisms responsible for the modulation of the heliosphere by coronal magnetic structure, and by the variable output of solar plasma and non-thermal particles associated with solar activity.

A detailed account of this preliminary study is given by Dr. A. B. C. Walker. This paper is included as Appendix I.

During the period of study a total of five meetings were held in various locations (i.e., Washington, DC; NASA/MSFC, Alabama; Boulder, Colorado). The minutes of these meetings were submitted to MSFC/NASA. We only include the essential parts of these minutes in the Appendix.

### III. Solar Beacon Facility

The Solar Beacon consists of a flat mirror in geostationary orbit, 1.25 meters in diameter, which is oriented in such a way that it forms an image of the sun on the earth's surface. It in fact acts as a reflecting pinhole camera. The solar image is sharp (about 0.1 arc second) and large (350 km diameter) on earth. An artist conceptual drawing is depicted in Figure 1. Using precise measurement techniques the shape and diameter of the sun can be determined to at least a precision of one to two parts in  $10^4$ . Measurements with this precision over periods of 10 years or longer are of great importance for the understanding of solar interior structure and

# SOLAR BEACON

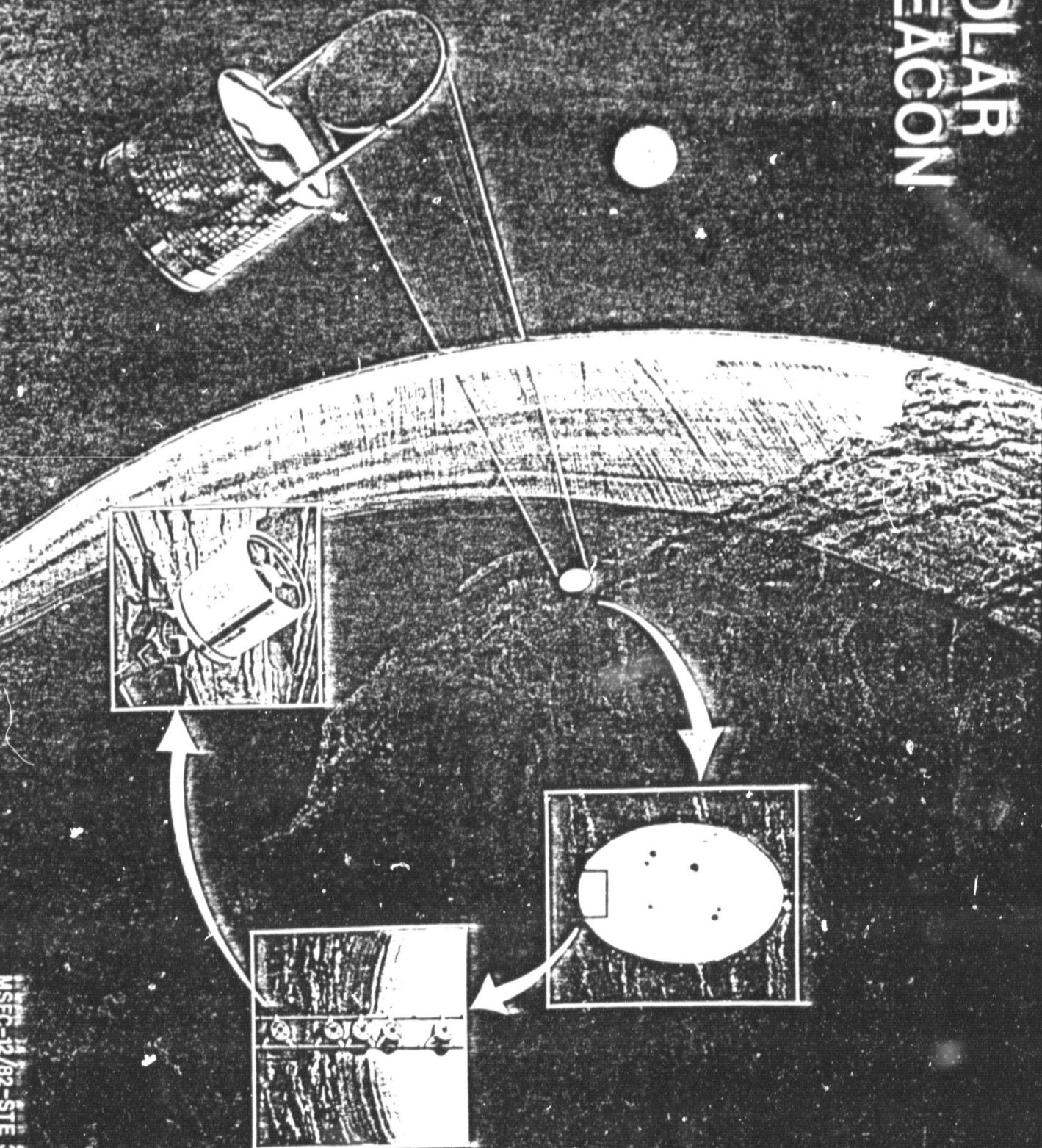


Figure 1. An artist conceptual drawing of Solar Beacon

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of solar variability.

A paper entitled "Measurements of Solar Diameter Using the Solar Beacon" was presented at the AIAA 21st Aerospace Sciences Meeting, January 10 - 13, 1983. A copy of this paper is included as Appendix IV.

On March, 1982, a document concerning the engineering aspect of the preliminary study of the solar beacon facility was published by the Program Development Office/Marshall Space Flight Center. Some of the important results are included in Appendix V.

During this period (September 1981 through June 1982) a total of three meetings were held. An account of these meetings are included as Appendix IV.

#### IV. Remarks and Recommendations

Since the first phase of this study, we conclude that ASO will be a major facility for solar research. In order to further our implementation of this plan the Science Study Group recommends that:

(i) A in-house study at MSFC is necessary to help the scientific community to determine some specific technology problems (this aspect of discussion will be included in the Chairman's Working Group Final Report).

(ii) Subcommittee activities should be closely coordinated with MSFC in-house activities.

APPENDIX I

List of Meetings for ASO

1st Meeting  
Washington, DC  
June 29, 30 - July 1, 1981

2nd Meeting  
NASA/MSFC, Alabama  
October 5 - 7, 1981

A meeting  
Boulder, Colorado  
January 10, 1982

3rd Meeting  
Washington, DC  
April 27 - 29, 1982

A Meeting  
Washington, DC  
December 2, 3, 1982

ADVANCED SOLAR OBSERVATORY (ASO) WORKING GROUP  
Minutes of Meeting No. 1

The first meeting of the Advanced Solar Observatory (ASO) working group was held at NASA Headquarters, Washington, D.C., June 29 and 30, and July 1, 1981. The meeting was co-chaired by Dr. A. B. C. Walker, Stanford University, and Dr. R. Moore, MSFC.

The other members are:

E. L. Chupp	S. Jordan
J. Harvey	
H. Hudson	
J. Kohl	
A. S. Kreiger	
R. W. Noyes	
R. Ramaty	
E. Rhodes, Jr.	
D. Sime	
G. Van Hoven	
G. Withbroe	

ex-officio

J. Ballance
S. T. Wu

The meeting, called to order by Dr. Walker, was followed by a presentation given by Dr. D. Bohlin, Chief, Solar and Heliospheric Physics Division/OSS, explaining the purpose of this working group and the agency's position. In addition, Dr. Frank Martin, Director, OSS, gave further information about NASA's long-term planning activities as well as the current climate for space science funding. Also, Mr. J. Ballance, MSFC, talked about the possibility of an engineering support study for the ASO.

ADVANCED SOLAR OBSERVATORY (ASO) WORKING GROUP

MINUTES OF MEETING #2

MSFC/HUNTSVILLE, ALABAMA

October 5-7, 1981

The second meeting of the Advanced Solar Observatory (ASO) Working Group was held according to plan at NASA/MSFC, Huntsville, Alabama, on October 5-7, 1981. A brief account of this meeting follows with an agenda and a list of attendees presented as Appendices I and II.

The meeting was called to order on October 5, 1981 by Dr. A. B. C. Walker and Mr. Bob Marshall, Director of PD/MSFC, welcomed the group and presented introductory remarks concerning the meeting. This was followed by a telephone conference with Dr. R. Canfield on the scientific objectives of the Solar Terrestrial Observatory with Drs. R. Chappel and E. Tandberg-Hanssen narrating the discussion. Copies of the viewgraphs are included as Appendix III.

Next, Mr. Bill Roberts gave a presentation on the space platform accommodations of the STO and the viewgraphs are included as Appendix IV. Following Mr. Roberts' presentation, the instrumentation subcommittee gave presentations on their findings. All written reports available on these presentations, as well as additional reports, are included as Appendix V.

On the second day of the meeting, the members of the committee continued discussions on the scientific objectives and engineering problems. In the afternoon, MSFC engineers were briefed on ASO technical problems as identified by the committee.

On the final day of the meeting, Chairman Walker gave a summary of the activities of the past two days, an outline of the ASO report, and assignments for team members. This information is included as Appendix VI.

It was decided to have a mini-meeting of the ASO Working Group in Boulder during the 1982 AAS meeting. The final meeting of the Working Group will be held at NASA Headquarters, Washington, D.C., in the Spring of 1982.

MEMORANDUM

February 2, 1982

TO: Members of Advanced Solar Observatory Scientific Study Team

FROM: S. T. Wu

SUBJECT: Minutes of Meeting, January 10, 1982, Boulder, Colorado

---

On January 10, 1982, members of the ASO Scientific Study Team met briefly at The University of Colorado campus. Dr. A.B.C. Walker, Chairman of the Team, presided over the meeting and the main discussion centered on the final report. Important items are listed as follows:

1. Instructions for the draft of the final report were distributed by Dr. Walker. The assignments and page allocation stated in the instructions were agreed to by all team members.
2. Memo No. 6 which included the revision of the outline of the final report was sent out by Dr. Walker the first week in January.
3. Schedule of time-table for draft of the final report
  - (a) H. Hudson will complete and forward his draft on Pinhole facility to Dr. Walker on January 22.
  - (b) A. Ramaty and D. Forrest are responsible for writing the High Energy Section about a configuration of the instruments during February.
  - (c) A. Walker is going to send another memo on assignments due for each individual team member the week of January 18. He will also send out revisions of Sections I and II. In addition, Dr. Walker will organize drafts of Sections III and IV and the Appendix.
  - (d) George Withbroe will examine EUV and XUV facility for ASO.
4. "Form" of final report - no decision has been reached at this point.

5.. Summary of present status by A. Walker

- Processing revisions of Sections I and II
- Writing Sections III and IV
- Memo concerning the present status will be sent out by Walker during the week of January 18

6. Next meeting could not be scheduled until team members have received draft of the final report.

7. It is the feeling of the team members that this team should be kept as a standing working group within the NASA planning structure.

8. Attendees - R. Ramaty  
H. Hudson  
A.B.C. Walker  
G. Withbroe  
R. Moore  
S. T. Wu  
D. Sime  
D. Forrest

ADVANCE SOLAR OBSERVATORY  
SCIENTIFIC WORKING GROUP MEETING  
NASA HEADQUARTERS, WASHINGTON, D.C.

April 27-29, 1982

MINUTES

Prepared by

S. T. Wu

The University of Alabama in Huntsville  
Huntsville, Alabama



The Advance Solar Observatory Scientific Working Group (ASOWG) held its third meeting on April 27-29, 1982, NASA Headquarters, Washington, D.C. A list of participants is included in Appendix I and the Agenda is in Appendix II.

The meeting was called to order by Dr. A.B.C. Walker, Chairman. The purpose of the meeting was to present the scientific rationale and status of ASO program development to the Division of Astrophysics, OSSA/NASA.

Dr. Walker gave an overview of the ASO which led to discussions on the scientific basis for the ASO program. In his presentation, the contemporary view of solar physics research and the role of ASO in solar physics research were discussed (Appendix III). In addition, Dr. Walker gave a presentation on the Solar Internal Dynamic Facility (SIDF) on behalf of Dr. Rhodes, a committee member who was unable to attend the meeting (Appendix IV).

The next scientific presentation was given by Dr. Harvey, who discussed the subjects of energy transport in stellar envelopes and atmospheres. His viewgraphs are included in Appendix V.

Dr. Withbroe outlined the essence of solar wind physics in relation to ASO and his viewgraphs are included in Appendix VI.

The final scientific presentation was concerned with heliospheric physics given by Dr. Sime. His viewgraphs are included in Appendix VII.

The above activities concluded our meeting of the first day.

On the second day of the meeting, April 28, the essential discussion was the draft report. During the discussion, Dr. Chupp presented a preliminary configuration of gamma ray facility. The other items discussed were as follows:

1. Promotion materials for ASO

Currently, the working group is thinking about three types of information material.

- (i) a simple brochure for the general public, congressional delegates, etc.
- (ii) a scientific report for the scientific community,
- (iii) a short document for NASA Headquarters/OMB officials.

2. General guidelines for ASO institutional development

3. Hardware configuration

Mr. Roberts gave a presentation regarding MSFC Engineering Study on the first day (Appendix VIII).

The last day of the meeting, April 29, was concentrated around the following subjects.

- 1. Individual assignments
- 2. Briefing scientific committees and making presentations in scientific meetings

- (i) CSSP Presentation: Harvey and Withbroe
- (ii) CSAA Presentation: Walker
- (iii) SSB Presentation: Hudson
- (iv) Boston AAS Meeting, January 1983
- (v) Pasadena Solar Physics Division Meeting, June 1983
- (vi) AIAA Science Conference, January 1983

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Recommendations

On behalf of the members of the working group, Dr. Walker will write a letter to Dr. Martin recommending the establishment of a Program Office for ASO in NASA Headquarters and at MSFC.

ADVANCE SOLAR OBSERVATORY  
SCIENTIFIC WORKING GROUP MEETING  
NASA HEADQUARTERS, WASHINGTON, D.C.

December 2-3, 1982

MINUTES

Prepared by

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The Advance Solar Observatory Scientific Working Group (ASOWG) held a meeting on December 2-3, 1982, at NASA Headquarters, Room 640, Washington, D.C. A list of participants is included in Appendix I and the agenda is in Appendix II.

The meeting was called to order by Dr. A.B.C. Walker, Chairman. The purpose of the meeting was to discuss the final document for the scientific and engineering concept and program development of the ASO.

Dr. Walker gave a brief summary of the results from the MOWG meeting which relates to the development of ASO. The working group then spent the remainder of the time working on the ASO final document.

The action items arising from this meeting are as follows:

- 1) Organization of study groups for individual ASO components. There are seven groups being established.
- 2) Study groups, group leaders, members
  - i) P/OF - Hudson (leader), Chupp, Hurford
  - ii) SSXRT - Krieger (leader), Walker
  - iii) SEUVT - Withbroe (leader), Noyes
  - iv) SXUVT - Walker (leader), Jordan
  - v) SIDF - Rhodes (leader), Harvey
  - vi) SHEF - Chupp (leader), Ramaty, Hudson
  - vii) SLFRF - Gergely\* (leader), Sime, Hurford

\* Dave Sime will contact Gergely

It was recommended that each group meet at Marshall Space Flight Center at least once to define specific requirements for their respective facilities. These group leaders will work with MSFC engineers during the next year to study each individual component within the context of ASO.

3) ASO should immediately begin Phase A study at MSFC.

4) An office should be established for ASO study.

The group was asked by Dr. Bohlin and Dr. Newton to recommend the ASO facility element which should be placed next in line for development.

There was extensive discussion on this issue with the outcome that the Pinhole/Occulter Facility and the Solar Soft X-Ray Telescope share equal priority. It was the opinion of the group that the two should be combined to form the X-Ray/Occulter Facility, and that element should be next in line for development for the ASO.

APPENDIX II

List of Meetings for SBF

1st Meeting  
Sante Fe, New Mexico  
September 28, 29, 1981

2nd Meeting  
Boulder, Colorado  
January 15, 16, 1982

3rd Meeting  
NASA/MFSC, Alabama  
June 2, 3, 1982

SOLAR BEACON SCIENCE STUDY TEAM MEETING

Santa Fe, New Mexico

September 28-29, 1981

NOTES

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The Solar Beacon Science Study Team met in Santa Fe, New Mexico for two days, September 28 and 29, 1981 to discuss all the aspects of the study. The meeting was cochaired by Drs. J. Beckers and E. Hildner. An attendee list and agenda are included as Appendix I. During the meeting, engineering aspects of Solar Beacon was presented by Max Nein and John Butler from MSFC/NASA. Their viewgraphs are included as Appendix II. The major subjects discussed among the team members are summarized in the following meeting notes.

The historical development of Solar Beacon was given briefly by J. Beckers (see working notes in NASA New Directions Symposium in Woodshole, June, 1980). The team members then spent two days discussing various subjects of Solar Beacon as follows:

#### I. SCIENCE OBJECTIVES

The general goal of Solar Beacon is to perform precision measurements of the solar diameter and shape as specifically outlined below:

- (i) Long-time evolution at a rate of 4% in  $10^9$  years means to observe solar evolution in a time scale of approximately 50 years.
- (ii) Multimillenia scale episodal mixing has been suggested in connection with the neutrino problem, the magnitude is about 2% over  $10^5$  years.
- (iii) Century scale type variation has great interest for solar-terrestrial effects such as the solar diameter and luminosity related to the Ice Age on Earth. Diameter effect now being investigated amounts to 0.01% per century.
- (iv) Variability of convective zone  $\left(\frac{\Delta D}{D} \sim 10^{-7}\right)$
- (v) Solar Cycle  $\left(\frac{\Delta D}{D} \sim 10^{-4}\right)$
- (vi) Sphericity of Sun  $\left(10^{-4} \sim 10^{-5}\right)$
- (vii) Pulsations of Sun  $\left(\frac{\Delta D}{D} \sim 10^{-5}\right)$

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(viii) Five minutes oscillation

(ix) Solar noise includes the study of granulation, super-granulation, plages, etc.

Items (i) through (vi) above are the prime science objective of the Solar Beacon.

## II. OPERATION MODES

(i) Stationary image mode

This operation mode consists of:

- Continuously adjusting mirror tilt to keep image at same Earth location
- Set of sensors around the limb measure shape using geodetic positions which will be able to give an accuracy of about 3 cm ( $\approx 0.3$  msa)
- Drift (dither) mirror (in East-West and North-South) to get limb shape
- Use small linear array to measure dither motion.

The advantages of this operation mode are:

- Better duty cycle needing smaller collectors and giving more flux
- Good for disk fine structure studies, but this will be capability of SOT
- Because of stationary image, there may be larger user community.

The disadvantages of this operation mode are:

- Difficult to account for annual change, thus complicating the ground station
- Accuracy limited by systematic errors to 0.5 msa
- Need to know  $\zeta$  (Zenith distance) well

- Scintillation may cause noise
- Different detectors on opposite limbs may cause some problems
- Complications in spacecraft design due to drift/dither of the image
- Sensitive to weather conditions

(ii) East-West image mode

This operation mode consists of:

- Rotate mirror around the axis perpendicular to equatorial plane
- Tilt mirror with respect to axis to have image pass over ground stations
- Observe only about  $\pm 3$  hours around midnight
- Measure cord length by timing (  $\sim 1-15$  ms)
- Calibrate by image repetition

The advantages of this operation mode are:

- Absolute, most straight-forward calibration
- Simple spacecraft
- How systematic errors in cord length/diameter determination, implying high precision being achievable over long periods of time
- Small number of ground stations needed

The disadvantages of this operation are:

- Use for fine structure studies is limited to very broad spectral band
- One needs to know  $\xi$  very well

In addition, there are some questions to be answered:

- What is high speed ( $> 1$  MHz) detector response?
- What is non-linearity of mirror rotation?
- Is elliptical mirror necessary?

- How well is small circle known and is it good enough ?
- How to adjust orientation during night optimization?
- Multiple detector to get non-linearities?
- Multiple small mirrors to get non-linearities (tolerance on angle)?

(iii) All position angle image mode

This operation was presented by M. Nein which consisted of:

- Systematically vary rotation axis of mirror to give scans of image in all directions
- Could be done by (a) putting axis in mirror surface and (b) putting axis in S-B-T plane
- Observe all night (?)
- Measure cord length by using rate gyros

The advantages of this operation are:

- Measure cords in all position angle
- No need to know  $\xi$
- It can be made to always give large circles

The disadvantages of this operation are:

- May give poor accuracy
- Complexity of the spacecraft

In addition, there are some questions to be addressed:

- Are rate gyros errors random or systematic?
- High speed detector response?
- Non-linearities of mirror motion rotation?
- Elliptical morrors necessary or not?
- Use repetition to calibrate (observes through diameter  $2^{\min} \equiv 6$  passes?)

### III. QUESTIONS TO BE ADDRESSED

(Persons Assigned)

#### A. Major

- What is the quality of the linear mirror rotation rate? This question can be examined in two parts: (i) What are the non-linearities in mirror rotation under no active control due to precession, nutation, reaction wheel, propellant motion, etc., and (ii) What are the non-linearities in mirror rotation under active control? (MSFC)
- Detector response time - This question includes the study of hysteresis, gain/phase as function of frequency. Specifically, we would like to know the characteristics of the responses to intensive pulses 15 ms long and the possible effects on beacon image size and beacon rotation rate. What are the characteristics of different detectors in terms of quantum effects, noise, area, and response speed ? (MSFC)
- How to determine  $\delta$  accuracy (MSFC, Bender)
- What is optimum spacecraft mode? (open)
- How much propellant is needed for station keeping of spacecraft? (MSFC) How is this related to the precision required?
- What is the solar noise? (Lites)
- Is solar pulsation (what period) a major science objective for Solar Beacon? (open)
- What are prime and secondary science objectives? (see Section I above)
- What is the reasonable flight duration in which to aim? Cost impact of 100, 30 or 10 missions? (MSFC)
- What is the operative mode for spacecraft and ground stations? (open)
- Should solar constant device be added? If added, should it be active or passive? (open)

- Pollution problem, environmental impact statements? Effects on nearby spacecraft (MSFC)

#### B. Lesser

- Effect of scattered light for fine structure studies and cord length studies. (Foukal)
- How to get image shape from 1D (E-W) cords and 2D (E-W, N-S, W-E) cords and what is the optimum ground array, etc.? (Ulrich)
- Use multiple mirror spacecraft? (open)
- Size of mirrors? Cost of 50, 100, 200 cm diameter mirror? (MSFC)
- Mirror deterioration due to particles, meteorites, radiation, propulsion, etc. (reflectivity, scattering, figure, MSFC)
- Is the start/stop mode an option and desirable? (open)
- What are the costs including spacecraft, ground station and operation?  
Can we think of it as an explorer class mission? (open)
- What are characteristics of scintillation as functions of time (frequency) and collecting amplitude (spatial frequency)? (Bender and Beckers)
- Do irregularities in mirror figure cause problems? (Beckers and Foukal)

#### IV. TASK ASSIGNMENTS FOR TEAM MEMBERS

See note on section III

- MSFC Engineering Team
  - What is best way to get linear rotation rate?
  - Detector response time?
  - Station keeping?
  - What is the reasonable flight duration to aim for?
  - Size of mirror?
  - Mirror deterioration?
- Bruce Lites
  - Solar noise

- Icko Iben and Roger Ulrich
  - Anticipated D-variation due to evolution, episodal mixing, convection zone changes, pulsations, etc.
- Jack Eddy and T. Brown
  - Suspected and observed D-changes due to solar cycle, sphericity, century time level change, pulsation, etc.
- T. Brown
  - Accuracy of ground based experiments
- P. Bender
  - $\delta$  determination
- R. Ulrich
  - How to get image shape from 1D or 2D cords?
- P. Foukal, T. Brown and B. Lites
  - Effect of plages on solar diameter
- J. Beckers
  - Visit MSFC to discuss the engineering and technical efforts.
  - Ground based operations
  - Effect of atmospheric refraction on limb shapes
  - Get accuracy of University of Arizona's diameter measurement.

SOLAR BEACON SCIENCE STUDY TEAM MEETING  
BOULDER, COLORADO  
January 15 - 16, 1982

NOTES

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The second meeting of the Solar Beacon Science Study Team was held in Boulder, Colorado for two days, January 15-16, 1982 (Friday and Saturday). The meeting was cochaired by Drs. E. Hildner and J. Beckers, respectively, during these two days. An attendee list and agenda are included as Appendix I. In the meeting, some results from MSFC's on-going study of engineering aspect of Solar Beacon were presented by J. Parker. His viewgraphs are included in Appendix II. Dr. Hildner announced that because of the NASA budget cut, only one more meeting of the SBSST will be held, instead of the two additional meetings originally scheduled. Thus, the team members spent one day discussing the outline of the team's final report and one day discussing various scientific aspects of the solar beacon facility. These contents are summarized in the following.

#### 1. Technical Presentations

Joe Parker (representing all the MSFC engineers) - The meat of the presentation is in the handouts in the Appendix, but several points are worth noting here.

Orbital mechanics simulation with a nearly "spherical" spacecraft (assumed moments of inertia similar in all three axes) shows that the expected nutation when the Solar Beacon spin axis is pointed  $11^\circ$  from celestial north is small (full amplitude builds up to 0.25 arc min in 6 hr). The nutation and rotation periods are similar (24 s and 20 s, respectively), unfortunately, for the assumed spacecraft, as they will always be if the spacecraft is nearly "spherical." The nutation arises from gravity gradient torques on the "non-spherical" spacecraft, which must spin about its axis of largest moment of inertia for the spin to be stable.

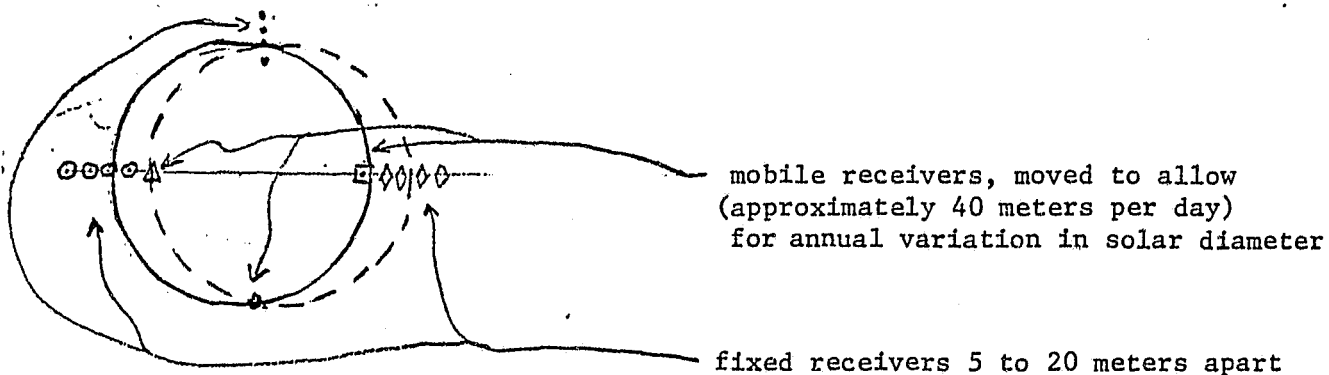
A star tracker pointed up the spin axis of the Beacon could control or monitor the spin axis direction to an accuracy of 1 arc sec.

In summary, the MSFC engineers believe no technological stoppers have yet been uncovered by their studies.

## 2. Scientific Discussion

2.1 P. Bender made a presentation on how the solar diameter and ablateness might be measured with a fixed solar image, occasionally moved slowly across the receivers. His summary for Solar Beacon with fixed image may be stated as follows.

- Limb profile and diameter determination ; About 20 fixed receivers, 5 at each limb plus 4 mobile receivers, arranged as in the sketch
- Telescope aperture ; greater than 24 inches
- Average time ; 2 min for  $1 \times 10^{-3}$  precision or  $1 \times 10^{-7}$  in solar diameter
- Mirror figure determination ; It is possible to map the figure of a 1 meter Beacon mirror from the ground by imaging 4th magnitude stars on ground detectors.



2.2 J. Becker's presentation covered the following topics:

### a. Atmospheric effects

1. Differential atmospheric refraction of north and south limbs will shift sun center about 27 cm on the ground; an ablateness of  $\sim 7$  cm is expected. These values assume the ground receivers are at Tucson's latitude.
2. Scintillation - caused by brightness fluctuations is small compared with photon noise.

- b. Ground-based detector array operation
- c. Effects of mirror; irregularities, no result at this moment
- d. Precision of ground base observation refer to H. A. Hill's paper at SPO Instrumentation Workshop "Solar Instrumentation: What's Next?", pp. 350-360, 1980.
- e. Photomultiplier  
PMTs have adequate sensitivity, collecting area, and response times. However, we still have no information whether hysteresis will be present due to a 15 msec flash of illumination.
- f. Air force study; forerunner of Solar Beacon

### 2.3 Accuracy of ground-based experiments.

T. Brown showed the team members his ground-based experiments at NCAR. Also, he has given a detailed discussion on the accuracy of the ground base experiment. He reviewed how one arrives at a solar limb definition and some of the consequences of various choices. Observing from under terrestrial atmosphere imposes constraints which the Beacon would avoid. Whether better, more accurate, measurements would result is not clear. Specifically, smoothing over the instrumental and atmospheric transfer functions and over limb roughness introduces a strong dependence on the presence or absence of structures well inside the limb.

For the benefit of the team, Brown presented his estimates of the limits to achievable accuracy imposed by several mechanisms.

#### Determination of Solar Diameter

<u>Mechanism</u>	<u>Tim Brown</u>	<u>Limit to Accuracy</u>
Solar "noise" or structure		10 to 20 msa in 8 hr (this is an underestimate, perhaps by 2X!)
Random seeing, differential refraction:		
transit instrument		12 msa
diameter instrument		0.5 msa
Systematic terrestrial atmospheric effects		10 to 100 msa (maybe?)
Calibration		1 msa

2.4 E. Hildner gave a presentation on Solar Beacon detector configurations. It looks promising that the use of multiple north-south receiver arrays could be used with a swept image to infer solar diameter and figure, because the image track and sweep speed could be well determined from ground observation alone. A note about this study is included as Appendix III. Following Hildner's presentation, R. Ulrich gave a short presentation on fitting solar figure curves to timing observations from such arrays.

2.5 Peter Foukal gave a presentation based on an Ap. J. Letter about to be published. He finds, observationally, that solar limb darkening curves vary by  $\leq 1\%$  over days, on some occasions, all the way from center to limb. Such solar behavior could materially affect any reasonable limb definition's placement of the solar limb.

As yet, there is no conclusion to be drawn about the effect of plages at or near the limb. Foukal will use a micro densitometer to study Miller's facular photographs to see if the faculae affect the height of the limb.

2.6 Lites discussed his work on modulation of apparent solar limb by granulation, etc.; a note about this discussion is included in Appendix IV. It appears that the limb will be systematically elevated due to the apparent super-position of oscillating elements along the line-of-sight.

2.7 P. Bender gave a brief discussion of the techniques he would propose for determination of the Beacon's zenith angle. For Beacon, we need to determine the relative distances to the Beacon from two ground stations to accuracies of 15 cm to get the position angles (latitude and longitude) of the Beacon in the sky. This is 3 times less critical (easier) than is being planned for geodynamics experiments. It is best done from widely separated ground stations using microwaves and an onboard transponder with a single channel at X-band. Distance to the Beacon is easy to measure to required accuracy.

At the conclusion of the technical and scientific discussions, there was consensus that although the Solar Beacon's attainable accuracy would not allow us to measure solar diameter changes on stellar evolution time scales, the Beacon could measure diameter changes on all other identifiable time scales and these measurements were worth pursuing. The final report will expand these conclusions and be based upon them.

### 3. Discussions on Final Report

It was suggested by Dr. J. Beckers and agreed by the team that the final report should comprise two documents; one document of approximately 25 pages will state concisely the scientific objectives and present technology. The other document will include all the substantiation for the brief descriptions in the concise document; it will also present the findings of the MSFC engineering team about engineering aspects of the Solar Beacon. The detailed outline of the final report and assignments to team members are described as follows:

#### 3.1 Outline of the Final Report (i.e., the approximate 25-page document)-

##### Chapter I. INTRODUCTION

- approx. 2 pages, to be  
written last

##### I.1 Science

##### I.2 Concept

##### I.3 Highlights of this experiment (or uniqueness)

#### II. THE SHAPE OF THE SUN

##### II.1. Review of present knowledge of the sun - approx. 2 pages, Eddy

##### II.2 Physical Mechanism Responsible for Solar Shape and Its Changes

##### II.2.1 Short introduction noting that the accuracy required to measure diameter changes on stellar evolution time scales appears unattainable - approx. 1 page, Beckers

## II.2.2 Specific Mechanisms

- a. Episodal mixing relating to neutrino problem  
(Kelvin-Helmholtz contraction) - approx. 1 page
  - b. Change in convective energy transport - approx. 1/1½ pages
  - c. Changes of magnetic energy in the interior - approx. ½ page
  - d. Solar rotation (i.e., depth and time variations) - approx. 1 page
  - e. Pulsation;  $2^h 40^m, 1^h$ , ---  $5^m$  - approx. 1½ pages
  - f. Surface convection - approx. 1 page
  - g. Surface magnetic disturbances; plages, sunspot - approx. 1 page, Foukal
  - h. Global or average atmospheric structures (Lites' work )  
approx. ½ page, Beckers
- Rhode  
Ulrich  
Iben
- Lites and Brown

II.3 Summary of Predicted Effects and Measurabilities - approx. 1 page, Beckers

## III. MEASUREMENT OF SOLAR SHAPE BY MEANS OF SOLAR BEACON

### III.1 Imaging by Solar Beacon

- a. Explanation of concept and some quantitative discussions;  
it also includes the effect of weather at ground-based  
stations - approx. 2 pages, Beckers
- b. Stationary image, including discussions of ground stations  
approx. 2 pages, Bender
- c. Swept image including discussions of ground station  
approx. 2 pages, Hildner/Ulrich

III.2 Definition of Solar Figure (limb definition and effects  
thereof) approx. 1½ pages, Brown

III.3 Detectors, Data Collecting and Analysis - approx. 1 page, Beckers

III.4 Achievable Accuracies Including Technological and Other  
Limitations

- a. Beacon measurements - approx. 1½ pages, Bender/Hildner
- b. Ground-based measurements - approx. ½ page, Brown

IV. COMPLEMENTARY OBSERVATIONS (for solar interior studies, etc.)  
with the Solar Beacon - approx. 2 pages, Foukal

V. SUMMARY, CONCLUSIONS and RECOMMENDATIONS - approx. 3 pages  
(to be written at June Meeting, total of 26½ pages)

VI. REFERENCES

3.2 Assignments

J. Beckers - I, II.2.1, II.2.2.1, II.3, II.1.a, III.3

J. Eddy - II.1

Rhodes, Ulrich, Iben - II.2.2.a.b.c.d

Lites and Brown - II.2.2.e.f

Foukal - II.2.2.g, IV

Bender - III.1.b

Hildner/Ulrich - III.1.c

Bender/Hildner - III.4d

Brown - III.2, III.4.b

3.3 Time table for submission of draft

2.3.1 April 25, 1982, all the drafts of the sections of the report  
by each individual are due to be mailed to other team members

2.3.2 Discuss the draft at June Meeting at MSFC

2.3.3 Complete review of the draft by mid-September, 1982

2.3.4 Final draft due December 1982

2.3.5 We should consider the possibility of special session at  
SPD Meeting, 1983.

3. Suggested MSFC efforts

3.1 Continue error budget analysis

3.2 How curved is the ground track of the swept image, how fast  
will the sweep speed change and how accurately can multiple  
north-south ground station arrays determine the track?

3.3 Can we oscillate the Beacon's mirror at a high (1 kHz) frequency  
on a fixed spacecraft?

3.4 How curved is the track swept by a ground station on the sky when projected back through the Beacon's reflection; i.e., in the vicinity of the sun, does the receiver sweep a straight or grossly curved line?

4. Action items accepted by team members

- A. Lites will give Brown theoretical limb profiles. Brown will pass these profiles through various limb definitions to see the effects of varying definitions.
- B. Foukal will microdensitometer Muller's photographs of faculae near the limb to see if the limb is elevated near or above faculae.
- C. Lites will consider the effects of chorompspheric structures on the limb as he has done for granulation.
- D. Lites will obtain a time-series of p-mode oscillation observations to see what happens to opacity as one looks parallel to the limb - April 1982
- E. All accept their writing assignments - mailed to team members on or before April 25, 1982.

5. Next meeting

June 2 and 3, 1982, Huntsville, Alabama

6. At the suggestion of Foukal and Eddy, it was agreed that the team should ask some more theoretically-oriented colleagues to review drafts of our report and perhaps to invite them to our next meeting. Those colleagues suggested are:

Bahcall  
Dicke  
Gilliland  
Gilman  
Grough  
Iben  
Press  
Roxburgh  
Weiss

SOLAR BEACON SCIENCE STUDY TEAM MEETING

Room 715, Building 4200  
Marshall Space Flight Center/NASA  
Huntsville, Alabama 35812

June 2-3, 1982

NOTES

Prepared by

S. T. Wu  
The University of Alabama in Huntsville  
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The third meeting of the Solar Beacon Science Study Team was held at Marshall Space Flight Center, Alabama, June 2-3, 1982. The meeting was cochaired by Drs. J. Beckers and E. Hildner, respectively. An attendee list is included as Appendix I.

The main tasks of this meeting, as stated by J. Beckers, were to address the following items:

1. What is the achievable accuracy of the measurements from a solar beacon?
2. Should we identify a prime mode and which should it be?
3. The nature of the final report of the study team and supporting documents.

After the general remarks made by J. Beckers, the group discussed the agenda of this meeting which was set as follows:

1. Discussion of achievable accuracy, i.e., consideration of the "Error Budget."

The "error" estimate prepared by the MSFC engineering team gives a starting point to assess achievable accuracy. Mr. J. Parker will review the estimate at this meeting. Not yet fully addressed in the MSFC "error" estimate are such items as:

- (i) Solar limb definitions and their consequences
- (ii) The intrinsic temporal and spatial variation of the position of the solar limb.
- (iii) Errors induced by spacecraft jiggle and geometrical considerations.
- (iv) Errors induced by uncertainties in the ground stations (e.g., locations, timing, detector response, etc.)

2. Consideration of the stationary versus swept modes of operation.
3. Discussion of the scientific objectives of the Beacon.

### I. Major Discussions

1. Bruce Lites presented his study on the temporal and spatial variation of the solar limb and its effects on solar limb determination. It is an excellent work and a scientific paper will result from this study.
2. Joe Parker and the team discussed the limits to achievable accuracy. Recasting the chart presented in MSFC's preliminary report to emphasize the distinction between systematic (always present) and random effects (diminishing as more data are averaged together). The final result of the discussion may be summarized in the following table, arranged to contrast the stationary and swept modes (Table I).

### II. Identified Future Tasks

As a result of the error discussion, areas were identified which affect accuracy and are not yet adequately analyzed. These should be studied before a final determination of achievable accuracy is made. Others need more study simply to define them, although accuracy is not affected.

1. Mirror figure, initial requirements, expected in orbit (thermal, particle bombardment, stress relief, etc.).
2. Rapid disturbances of spacecraft (i.e.  $\sim 10$ -15 Hz).
3. Tracks of detectors across Sun in both stationary and swept modes.

4. Detector response (photomultiplier speed, sensitivity, hysteresis, etc.).
5. Contrast accuracy benefit which accrues from fitting a figure curve to multiple-detector chord measurements with measuring one or more diameters.
6. Costing study of space-related components.
7. Data archiving and processing requirements, procedures, and necessary resources.
8. Ground station configuration.

### III. Review of Draft Portions of Final Report

During discussion of the portions of the final draft already circulated to Team members, several modifications and revisions were suggested. In the end, it was concluded that review, page by page, of the draft portions of the Report was inefficient at this time, and that it could be better reviewed when the co-chairmen of the Team have pulled the various portions together into a more readable, cohesive form.

During the discussions, some questions arose and Team members accepted assignments to discover answers.

- Foukal offered to call Henry Hill and inquire if SCLERA observations were taken simultaneously with his limb darkening observations at KPNO. If there are simultaneous observations, Foukal will try to examine further the effect of limb darkening curve variations upon Hill's "diameter" measurements.

- Rhodes will find out what is the expected change in radius due to solar oscillations in the ~ 5-minute period range.

- Nein will ensure that a costing study will be performed, at a level of detail consistent with the engineering studies on which it will be based.

- Parker will revise his "Error Budget" in line with the Team's discussions during the meeting.

Systematic

Swept

Stationary

Comparison

Geometric effects

0.25

0.25

~ Same

Point spread function (goal)

0.25

0.25

Easier to image a star  
in stationary mode, if  
this is desirable

Uncertainty of shape arising from  
uncertainty in detector tracks  
across disk

0.05

N/A

Detector time response

0.2

N/A

Sweep velocity

0.2

N/A

Clock precision (relative)

0.05

N/A

Uniformity of collector mirror

0.1

0.05

Unclear

Detector passband ( $\Delta\lambda$ )

?

?

Unclear

Limb definition(s) chosen

?

?

Unclear

Random

Limb darkening noise and center  
fluctuation of 0.3% (limb defined  
as fraction of  $I_0$ )

0.1  $\rightarrow$  0.25 msa/ $3^d$

0.1  $\rightarrow$  0.25 msa/ $3^d$

About equal

Quiet Sun noise (local limb definition)

10 msa/pass  
2 msa/avg over  $5^m$

2 msa/ $5^m$

About equal

Photon noise

TBD

TBD

Scintillation

N/A

TBD

Detector sensitivity variations

TBD

TBD

Servo control of non-rotating spacecraft

-

preferable

Less than 2m diameter mirror

-

preferable

Mobile detectors must be moved daily

preferable

-

ORIGINAL PAGE IS  
OF POOR QUALITY

#### IV. Stationary versus Swept Mode

This discussion was a part of much of what else was discussed at the meeting, but is pulled together here for ease of comprehension.

The stationary mode requires a servo loop from sensors on the ground providing correction signals to active attitude controllers on board the Beacon. The Beacon's mirror should not flop or jiggle at periods shorter than the servo loop control time ( $\sim 1/4$  sec). In this mode, also, the short strings of relatively simple ground stations would not be routinely sensing a limb darkening curve, and some stations would have to be mobile to accommodate the change in the solar image size. By integrating over longer times, the collector area and the Beacon mirror diameter could both be smaller than for the swept image case. The possibility to direct the stationary image to existing stellar observational facilities for precise analysis of light from particular, highly resolved solar features is intriguing. The closed loop servo to keep the solar image stationary requires continuous radio contact with the Beacon.

The swept image, on the other hand, requires that the motion of the Beacon be smooth over the 15-20 msec during which the image sweeps over the detector's arrays. The physical separation of the detector arrays is less, and more shape information is presumably obtained since measurements occur at more points around the limb. Timing is more of a problem, as is the number of signal photons in a measurement interval. At a Beacon rotation rate of 0.05 Hz, there are concerns about photomultiplier response characteristics. While there would have to be continuous ranging to the Beacon in this mode as for the stationary mode, there is no requirement for continuous, active response by the attitude control system.

A straw poll of the Team indicated that although there were no strong feelings about the superiority of one mode over the other, the consensus view was that the stationary mode was easier to explain and might be easier (and cheaper?) to implement.

Therefore, the Team decided that the Final Report would explain the Solar Beacon experiment as a stationary, 50 inch mirror (same size and hence same resolution as SOT) in geosynchronous orbit, with 2 fixed and 6 mobile detector arrays on the ground at the cardinal and inter-cardinal points of the image. The mission life will be assumed to be 10 years.

#### V. Post-Meeting Activities

(A) Beckers and Hildner met 4 June to discuss the form of and the effort on the Final Report. It was agreed that there was not enough information obtained since the previously distributed outline to warrant changes to the report outline given in the minutes of the previous meeting. Beckers and Hildner split the editing responsibility and they will prepare a more or less complete draft before requesting comments from Team members. An inventory of desirable supporting documents was drawn up and the existence of or need to create each one was determined. Fortunately, most of the supporting documents already exist.

In conjunction with Max Nein, Beckers and Hildner discussed the artwork which would be useful in explaining the Beacon concept in future presentations to audiences less familiar with the idea. There was agreement that the notion of a Solar Beacon to measure solar diameter was not well-known in the scientific community and that presentations should be made at frequent opportunities to acquaint interested persons with the concept.

(B) Action Items

- Foukal will call Hill regarding possible simultaneous SCLERA and KPNO measurements of limb darkening. He will examine simultaneous measurements to see if limb darkening affects Hill's measurements.

- Rhodes will talk to Ulrich and others regarding the size of the change in solar radius in the frequency range.

- Nein will oversee the production of artwork at MSFC.

- Beckers and Hildner will edit the draft Final Report and distribute it for comments.

APPENDIX III

# AIAA'83

**AIAA-83-0511**

**The Advanced Solar Observatory**

A.B.C. Walker, Jr., Stanford Univ., Stanford,  
CA

**AIAA 21st Aerospace Sciences Meeting**

January 10-13, 1983/Reno, Nevada

## THE ADVANCED SOLAR OBSERVATORY\*

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Abstract

The Advanced Solar Observatory (ASO) is a proposed long duration space observatory which would be placed on a Space Shuttle serviced Space Station or space platform. The ASO will consist of a collection of major telescopes and detectors which can observe the full range of electromagnetic emissions of the Sun, from low frequency radio waves to high energy gamma rays. Because of the large instrument apertures made possible by the size and weight carrying capacity of the Space Shuttle, the ASO will allow the Sun to be studied with unprecedented resolution and sensitivity, and will provide new insights into virtually every major problem confronting solar physicists.

I. INTRODUCTION

Our motivation for studying the Sun comes from several sources. First, the Sun occupies a unique position in astrophysics, because it is the only star which can be examined in sufficient detail to allow stellar phenomena to be studied at the level of the basic atomic physics, nuclear physics, plasma physics, and magnetohydrodynamic processes which underlie these phenomena. The Sun is, in effect, a laboratory which we can utilize to study the physics of stars. Second, the Sun is the predominant factor in shaping the interplanetary space within the solar system; in fact, this region of space is now generally referred to as the heliosphere to emphasize the primary role of the Sun. The heliosphere, and its interaction with planetary magnetospheres, ionospheres, and atmospheres, is the subject of the discipline of space physics; the connection between solar physics and space physics is no less profound and fundamental than is the connection between solar physics and astrophysics. Finally, the Sun has a profound influence on the earth's ecosphere, and hence on humanity. Life on the earth is possible only because of the Sun, and our lives depend principally on the use of solar energy, either stored or ambient. Furthermore, in the past several years, evidence has steadily mounted that the variability of the Sun, which is represented by but by no means limited to the well-known sunspot cycle, can significantly affect conditions on the earth on time scales of centuries and millennia, and perhaps on shorter time scales as well.

\* A NASA sponsored Science Definition Team (SDT) is presently working with the Marshall Space Flight Center (MSFC) to refine the concept of the ASO. The present paper is based on the draft report of the SDT, which will be published shortly by MSFC. The membership of SDF, of which the author is chairman, represents 13 major solar research groups.

\*\* The author is Professor of Applied Physics

In the past two decades, observations of the Sun from space observatories have greatly enhanced our understanding of solar phenomena, and of their connections to the other disciplines cited above. With the advent of the Space Shuttle, and the prospect of serviceable Space Stations (or space platforms) in earth orbit, we stand at the threshold of a new era of greatly enhanced observational capability which will allow a much deeper understanding of solar phenomena to be achieved. In this paper I describe a developmental program for a new long duration Space Shuttle serviced space observatory, the Advanced Solar Observatory (ASO). The concept of the Advanced Solar Observatory presented here is the principal recommendation of the Astronomy Survey Committee, and its Working Groups and Panels<sup>1,2</sup> which is relevant to solar physics. The Advanced Solar Observatory is conceived as a comprehensive collection of high resolution instruments capable of observing the full spectral range of electromagnetic radiation emitted by the Sun. The ASO will consist of four major instrument groupings or facilities:

- A High Resolution Solar Telescope Cluster which will carry out high resolution studies of the Sun's interior dynamics (by observing the global oscillations of the Sun), and the solar photosphere, chromosphere and low corona, at optical, ultraviolet, extreme ultraviolet, XUV, and soft x-ray wavelengths.
- A Pinhole/Occulter Facility for the study at high angular resolution of the outer corona and the solar wind at optical, ultraviolet and extreme ultraviolet wavelengths, and of transient phenomena such as flares at hard x-ray energies.
- A Solar High Energy Facility for spectroscopic observations of transient phenomena at hard x-ray and gamma ray energies, and for the study of solar neutrons.
- A Solar Low Frequency Radio Facility for the study of particle acceleration and propagation in the corona and inner heliosphere.

The solar physics community proposes to develop this comprehensive observatory by an evolutionary process, by first developing and deploying on Spacelab (the Space Shuttle attached laboratory) a core of full scale, but simplified ASO component instruments. These Spacelab instruments will later evolve into the mature long duration Advanced Solar Observatory. This process has already begun, with the initiation of the development of the Solar Optical Telescope (SOT), the first component of

the High Resolution Solar Telescope Cluster.

Among the major scientific problems which the Advanced Solar Observatory will allow us to address in a fundamental way are:

- The development of techniques which can provide direct empirical tests of models of the internal structure and dynamics of the Sun.
- The elucidation of the apparently central role played by magnetic reconnection and particle acceleration in solar flares, and in other explosive phenomena in astrophysics.
- The identification and study of the mechanisms responsible for heating the solar corona.
- The identification and study of the mechanisms responsible for the acceleration, structure, and composition of the solar wind.
- The identification and study of the mechanisms responsible for the generation of the solar magnetic field, and the operation of the solar activity cycle.
- The identification and study of the causes of long-term variations in the solar magnetic and activity cycles.
- The elucidation of the mechanisms responsible for the modulation of the heliosphere by coronal magnetic structure, and by the variable output of solar plasma and non-thermal particles associated with solar activity.

In order to effectively investigate these major problems, the Advanced Solar Observatory must have a combination of angular resolving power (to isolate fine structure in the solar atmosphere), spectral resolving power (to allow diagnostic observations of physical processes) and temporal resolving power (to study rapidly varying conditions and indicators associated with phenomena such as wave propagation and particle acceleration) which matches the physical and temporal scales of solar phenomena. Table I demonstrates quantitatively, in a few selected areas, the significant advances in observational capability, amounting in many instances to improvements of an order of magnitude or more, which the Advanced Solar Observatory can achieve.

In addition to the advantage in resolving power, sensitivity and spectral and temporal resolution, the Advanced Solar Observatory offers the enormous advantage of simultaneous observation in all temperature domains (by virtue of complete simultaneous wavelength coverage) of importance in the solar atmosphere.

## II. SCIENTIFIC MOTIVATION FOR THE ADVANCED SOLAR OBSERVATORY

The Sun presents us with a very nearby sample of astrophysical material, lying figuratively on our very doorstep. Its brightness is so great that observations with extremely high spectral and temporal resolution, and high signal-to-noise, are attainable throughout the electromagnetic spectrum. In addition, angular resolution as good as one ten-thousandth of the solar diameter is attainable. Furthermore, by remote and in situ observations of the interplanetary medium, we can study physical processes occurring in solar material at a level

Table I Comparative Observational Capability

Wavelength Domain	Solar Property Probed	ASO Resolving Power & Property Measured	Comparison Instrument & Its Capability
Visible	Atmospheric Dynamics	spatial structure: 70 km	SPO Vacuum Tower: 250 km
Ultraviolet	Mass Transport	spatial structure: 35 km	SMM*: 1000 km
Visible	Internal Dynamics	velocity: 1 m/sec	KPNO McMath: 100 m/sec
EUV	Dynamics of Spicules	spatial structure: 150 km	ATM**: 3500 km
Soft X-Ray	Dynamics of Coronal Loops	spatial structure: 350 km	SMM***: 10,000 km
		spectral resolution: 10,000	SMM: 2000
Hard X-ray	Flare Dynamics	spatial structure: 150 km	SMM: 3500 km
EUV/XUV	Solar Wind Acceleration	spatial structure: 1000 km	ATM: 14,000 km
		velocity: 5 km/sec	No Previous Capability

\* Solar Maximum Mission

\*\* Apollo Telescope Mount on Skylab

\*\*\* The ATM Soft X-ray telescopes achieved a resolution of 2000 km in broad wavelength bands.

of detail which rivals that which can be achieved in laboratories on earth. This makes the Sun a superb astrophysical testing ground, both for new theoretical concepts and for new observational techniques. Consequently, we believe it is possible to make real progress in understanding how matter and magnetic fields interact in the Sun and in astrophysical plasmas in general, by studying matter-field interactions in the Sun and in the heliosphere at a deeper level than has been achieved so far. We may discuss the scientific program of the Advanced Solar Observatory (ASO) under two major headings, stellar physics, and heliospheric physics.

#### Stellar Physics

The impressive accomplishments of the 1970's and early 1980's in solar imagery and spectroscopy at the several arc-second level have revolutionized our perception of the Sun as a magnetic star, and at the same time have pointed the way to an understanding of similar magnetic effects in other stars (e.g. magnetically-heated coronae, stellar winds, etc.) and in non-stellar objects (e.g. accretion disks surrounding degenerate stars or the cores of active galaxies). True understanding of the magnetohydrodynamic processes occurring in stellar envelopes, and on and above stellar surfaces, however, awaits a more detailed view of these interactions on the spatial scales where the fluid-magnetic field interactions actually occur. This scale is finer than the arc-second resolution attained so far on the Sun, and on other astrophysical objects; however, diagnostic observations at the appropriate scales will become possible for the first time with the Advanced Solar Observatory. Clearly, improved theories of stellar envelopes and atmospheres must be based to a large degree on solar models.

The Sun has also played a key role in the development of our current theories of interior structure, dynamics, and energy generation in stars, and of the transport of energy from the interior to the stellar surface where it is radiated away. These theories, although based on idealized stellar models which do not include stellar rotation, and which treat such phenomena as the convective transport of energy in the envelopes of cool stars in an ad hoc manner, have been remarkably successful in describing the basic properties and evolutionary development of the majority of stars. However, the advent of new observational techniques and results, such as the unexpectedly low flux of high energy neutrinos from thermonuclear reactions in the solar core observed by the Chlorine Radio Chemical Detector deep underground in Lead, South Dakota, has raised new questions about the internal dynamics of stars, which demand the development of improved theories of stellar interiors based on more realistic assumptions. Already, extremely precise velocity measurements, possible only on the Sun, are beginning to reveal signatures of

the deep interior that will be critical to the development of these improved theoretical models.

Summarizing, the development of improved stellar models will involve two basic scientific objectives:

- The development of observational techniques that can probe the structure, composition, and motion of matter in the solar interior where energy is generated and transported to the solar surface, therefore providing direct experimental tests of theories of stellar structure, dynamics, and evolution.
- The detailed study of the various active phenomena that can be observed in the solar atmosphere. These active phenomena are consequences of the generation of magnetic fields and of large-scale circulation, which are themselves by-products of energy transport processes operating in the convective envelope of the Sun.

The Advanced Solar Observatory will play a dominant role in both of these scientific programs.

#### Heliospheric Physics

A third major scientific objective of solar physics is;

- The study of the three dimensional structure and dynamics of the heliosphere, including investigations of the physical processes involved in generation of the solar wind, coronal mass ejections, particle acceleration and propagation, and shockwaves in the solar wind.

These studies are closely related to studies in space physics and the physics of stellar coronae and stellar mass loss.

The solar wind is by far the best observed of the expanding hydromagnetic flows that are important in many astrophysical systems, such as globular clusters, galactic halos, and close binary star systems. The solar wind provides an opportunity to study plasma structures such as waves, discontinuities, and shocks which are important in other astrophysical plasmas but are not accessible because of their remoteness. Many of these phenomena cannot be studied in the laboratory because they do not occur on laboratory scales; the heliosphere provides the only opportunity to study these processes in detail.

Because the solar wind controls all of the varied processes within the heliosphere, the study of the production and variation of the solar wind is essential to understanding the structure and dynamical behavior of the heliosphere itself, and of the magnetospheres,

ionospheres, and atmospheres of the planets. The ASO will play a key role in the study of the heliosphere because of its capability to observe the global structure, flow, and dynamics of the solar wind, and to relate these characteristics to phenomena occurring in the corona and chromosphere.

The control of the structure of the earth's magnetosphere and ionosphere by the solar activity cycle is a well established fact. The principal influence of the Sun on the lower atmosphere of the earth is, of course, the heating produced by sunlight. The variation of climate over the past centuries has raised questions as to precisely how steady is the supply of sunlight to the upper atmosphere, and how steady is that part which penetrates to the lower atmosphere of the earth. Recently, variation of the level of the solar output of a few tenths of one percent over periods of days have been discovered. The ASO in collaboration with the Solar Terrestrial Observatory<sup>3</sup> will greatly refine and extend these precise observations of the fluctuations of the solar output, and will relate them to variations occurring within the envelope and in the atmosphere of the Sun. The ASO will, therefore, play an important role in the newly developed interest in the coupling between solar variability and climate.

#### The Role of the Advanced Solar Observatory

The key role of the Advanced Solar Observatory in each of the fundamental scientific objectives we have identified can be illustrated by considering a specific example. The upward flowing gas jets called spicules associated with the boundaries of large scale convection cells (supergranulation) on the Sun are indicative of the complexity of the phenomena which the ASO will investigate (Figure 1). The spicules are an example of a class of phenomena which we believe play a central role in the solar atmosphere, specifically, in this instance, in the dissipation of mechanical energy generated by convective processes in the photosphere and in the exchange of mass between the chromosphere and corona; but which operate on a scale which is too small for observations obtained with present instruments to test detailed physical models. In order to study the causes, structure, and dynamical behavior of spicules, and their role in the mass and energy balance of the solar atmosphere, we must observe their magnetic structure (using the Solar Optical Telescope (SOT)), their relationship to the convective processes occurring beneath the photosphere (using the Solar Internal Dynamics Facility), the flow of mass within the spicules themselves (using the Solar EUV Telescope) and the structure and dynamics of their interface with the corona (using the Solar XUV Telescope). Furthermore, in order to understand the role of spicules in the mass balance of the atmosphere, we must understand the global nature of the interface of chromospheric material (as represented by the spicules) with the corona and solar wind. This will require the capabilities

of the Solar Soft X-ray Telescope and the Pinhole/Occulter Facility.

In order to guide the development of models of spicules, and of the other structures which control the flow of energy and mass in the solar atmosphere, and to provide the necessary critical observational tests, we must have the capability to determine observationally the fundamental parameters of the solar plasma: ionization structure and elemental composition, microscopic and macroscopic velocity distributions, magnetic and electric field strength, on the physical scales at which the fundamental plasma processes occur in such structures. The physical scale which must be resolved is determined by the distance over which substantial changes in these fundamental parameters occur, this characteristic distance is determined by several factors; the atmospheric scale height, ( $\sim 200$  kilometers) at the photosphere, the mean free pathlength of photons ( $\sim 40$  kilometers at the photosphere), and the turbulent diffusion length ( $\sim 50$  kilometers at the photosphere). The



Figure 1. A field of spicules photographed near the limb of the Sun. (Courtesy of the Sacramento Peak Observatory)

observational program which we have set for the ASO will, therefore, require instrumentation capable of fundamental diagnostic observations with resolving power corresponding to a fraction of these characteristic lengths, i.e., scales of 35-70 kilometers in the photosphere and chromosphere (this corresponds to a resolving power of 0.05-0.1 arc-seconds at the earth's orbit); this is a full order of magnitude beyond our present capability, but is within the capabilities of the ASO.

### III. THE CONFIGURATION OF THE ADVANCED SOLAR OBSERVATORY

The basic ASO configuration may be thought of as an ensemble of four instrument groupings or facilities; the individual instruments in each grouping have common packaging and support requirements. These instrument groupings are 1) the High Resolution Solar Telescope Cluster which will contain the Solar Optical Telescope, the Solar Soft X-ray, EUV, and XUV Telescopes, and instrumentation to study the interior dynamics of the Sun, 2) the Pinhole/Occulter Facility, which will contain instruments requiring a long focal length, either for external occultation or for high resolution transform or diffraction imaging techniques, 3) a Solar High Energy Facility for gamma ray and hard X-ray observations which do not require high angular resolution, and 4) a Solar Low Frequency Radio Facility. The design and performance parameters of each component of the

ASO are given in Table II. The configuration of the Advanced Solar Observatory, as it might appear deployed in space, is illustrated in Figure 2. A developmental version of the ASO, consisting of the High Resolution Solar Telescope Cluster, the Pinhole/Occulter Facility and a moderate sized Solar Gamma Ray and Neutron Spectrometer (which will be placed inside the High Resolution Solar Telescope Cluster) will be operated as a Shuttle Attached payload before the full ASO is deployed on a space platform or Space Station. The individual components of the Advanced Solar Observatory which will be developed initially as individual Spacelab facilities have in most cases, been studied in some depth by previous NASA Definition Teams; consequently, the configuration of the individual ASO component instruments can be specified in some detail. In the following discussion, the configuration and operation of each of the major components of the ASO is reviewed.

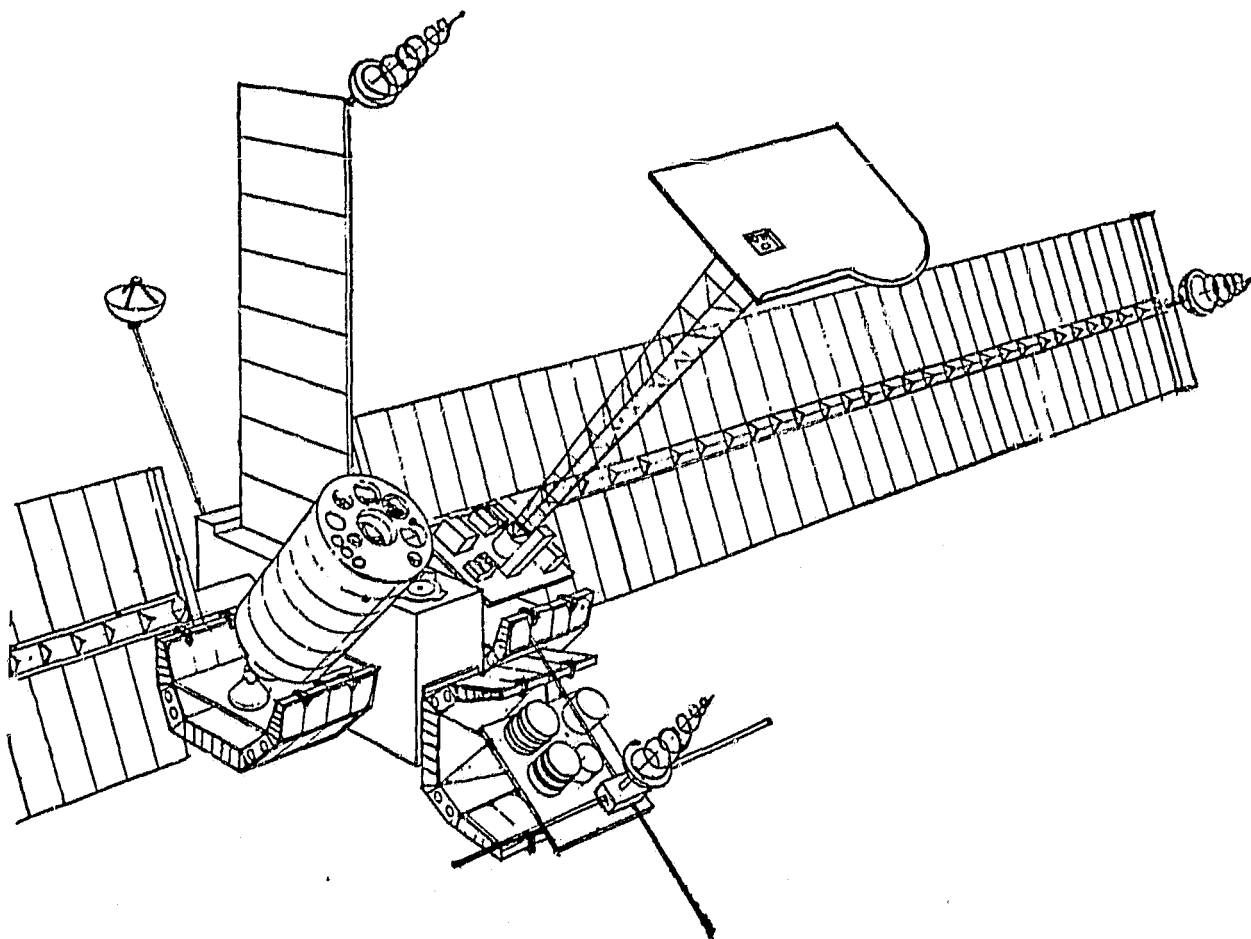


Figure 2. The ASO is shown mounted on a space platform, utilizing Shuttle pallets and the Spacelab Instrument Pointing System (IPS). The High Resolution Solar Telescope Cluster is on the left, and the Pinhole/Occulter Facility at the upper right. The Solar High Energy Facility and part of the Solar Low Frequency Radio Facility share the pallet at the lower right. Additional low frequency radio arrays are mounted on the thermal radiator and solar panels. (Courtesy of the Marshall Space Flight Center)

TABLE II  
Major Components of the Advanced Solar Observatory

Instrument	Wavelength Coverage	Aperture (cm)	Resolving Power	
			Angular arc-sec/km <sup>6</sup>	Spectral $\lambda/\Delta\lambda$
<b>High Resolution Solar Telescope Cluster</b>				
Solar Optical Telescope (SOT)	1100-11,000Å	125	0.05/35	600,000
Solar EUV Telescope (SEUVT)	500-2000Å	90	0.3/200	30,000
Solar XUV Telescope (SXUVT)	100-800Å	40	0.5/350	30,000
Solar Soft X-ray Telescope (SSXRT)	1.5-300Å	80	1.5/350	20,000
Solar Gamma Ray and Neutron Spectrometer (SGRNS) <sup>1</sup>	10keV-10MeV	50	full sun	1,000
Guest Instrumentation Accommodation <sup>5</sup>	-	100 <sup>2</sup>	-	-
<b>Internal Dynamics Facility (SIDF)</b>				
Fourier Tachometer/Magnetograph (FT/M)	3500-7500Å	30	4/3000	100,000
Helioseismometer (HSM)	3500-7500Å	20	6/4000	5,000
Differential Radiometer (DR)	4000-7000Å	15	60/40,000	5
Radial Seismometer (RSM)	1100-1400Å	1000 <sup>7</sup>	0.0015/1	5
Integrated Light Spectrometer (ILS)	5896 Å	10	full sun	1000
Irradiance Data <sup>8</sup>	1 - ∞Å	various	full sun	6000
<b>Pinhole/Occluder Facility (P/OF)</b>				
White Light Coronagraph (WLC)	4000-9000Å	50	1.5/1000	5000
EUV Coronagraph (EUVG)	300-1700Å	50	1.5/1000	20,000
High Resolution Hard X-ray Imager (HRIHXRI)	2-100keV	3000 <sup>3</sup>	0.4/300	20
High Sensitivity Hard X-ray Imager (HSHXRI)	2-100keV	12000 <sup>3</sup>	15/10,000	20
<b>High Energy Facility<sup>4</sup> (SHEF)</b>				
High Resolution Spectrometer (HRS)	100keV-10MeV	50	full sun	1000
High Sensitivity Spectrometer (HSS)	100keV-10MeV	100	full sun	50
High Energy Gamma Rays Spectrometer (HEGRS)	10MeV-1000MeV	100	full sun	100
High Energy Neutron Spectrometer (HENS)	10MeV-1000MeV	100	full sun	100
<b>Low Frequency Radio Facility<sup>4</sup> (SLFRF)</b>				
Crossed Dipole Array (CDA)	1-20MHZ	6000	10°	200
Log Periodic Array (LPA)	1-20MHZ	20000	3°	200

1. HRSTC compatible prototype Gamma Ray Facility for the initial ASO deployment on the Shuttle
2. Maximum Instrument Diameter
3. Detector Area
4. Advanced Facility for deployment after completion of the Shuttle Attached phase of the ASO program
5. Accommodation for specialized instruments such as an X-ray polarimeter or a high resolution hard X-ray spectrometer for specific observing programs.
6. Size of feature on the sun which can be resolved
7. Interferometer which will use aperture synthesis techniques
8. The required irradiance data will be obtained from measurements carried out by a companion facility, the Solar Terrestrial Observatory

#### The High Resolution Solar Telescope Cluster

The High Resolution Solar Telescope Cluster will contain those components of the ASO which utilize focusing optics, and which require precise and stable pointing at the solar disk in order to carry out their research programs. The HRSTC instruments are mounted on a Central Spar which contains the SOT mirror, as shown in Figure 3. The major components of the HRSTC are:

- 1) The optical/ultraviolet telescope facility, the Solar Optical Telescope (SOT), with a 125 centimeter primary mirror mounted in a Gregorian configuration.
- 2) The Solar Soft X-ray Telescope, with an 80 centimeter Wolter-Schwartzschild I mirror
- 3) The Solar Extreme Ultraviolet Telescope, with a 90 centimeter primary mirror mounted in a Gregorian configuration.

- 4) The Solar XUV Telescope, with a 40 centimeter Wolter-Schwartzschild II Mirror
- 5) The Solar Internal Dynamics Facility containing wide field visible light telescopes and irradiance monitors intended to study the structure of the solar interior and the phenomenology of the solar activity cycle
- 6) A Solar Gamma Ray and Neutron Spectrometer, which is a precursor to a larger Solar High Energy Facility

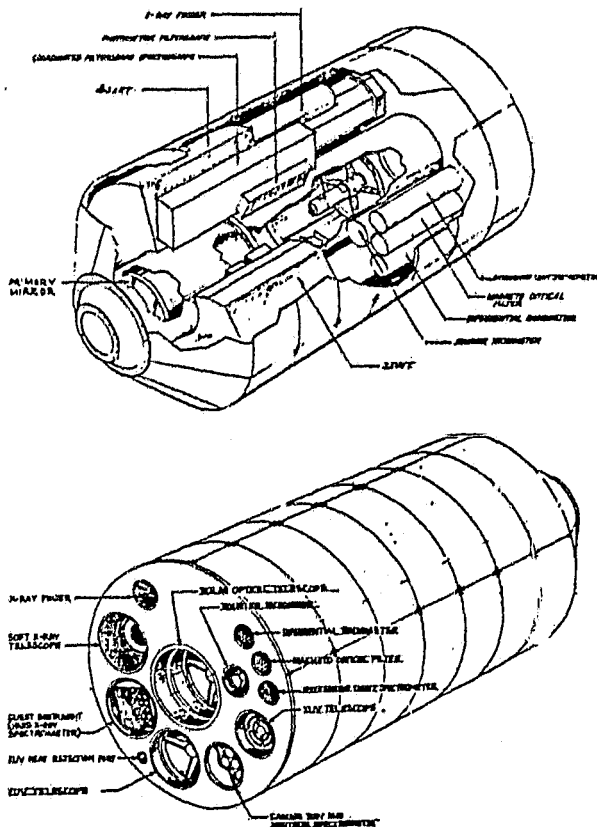


Figure 3. Two views of the High Resolution Solar Telescope Cluster. The HRSTC is 4 meters in diameter and 7.5 meters long. Note the annular volumes intended for the focal plane instruments of the SSXRT and SXUVT visible in the upper figure. (Courtesy of the Marshall Space Flight Center)

In addition to the six major instruments, the HRSTC can accommodate a major "guest instrument", such as an X-ray polarimeter or a hard X-ray spectrometer, for a program of collaborative observations with the permanent ASO instruments aimed at a specific scientific problem.

**The Solar Optical Telescope:** The principal scientific justification for the Solar Optical Telescope, and the major guiding motivation in its design, is the need to achieve resolving

power sufficient to observe phenomena in the solar atmosphere on the scale over which changes in the collective behavior of the atmosphere occur. The diffraction limited resolution of the SOT 125 centimeter mirror is equivalent to 70 kilometers at 5000Å, and the performance of the SOT mirror should exceed 35 kilometers at the short wavelength cutoff, 1100Å. The SOT primary mirror feeds an on-axis Gregorian configuration, which allows the use of a heat rejection mirror at prime focus. The Gregorian configuration, with the f/3.6 primary parabolic mirror, results in less obscuration of the aperture by the secondary mirror, thereby allowing the sharpest possible image. Except for field curvature (which is insignificant for small fields) aberrations for the SOT mirror will be negligible. The SOT design utilizes an articulated primary mirror to maintain coincidence of the conic foci of the primary and secondary mirrors, and to provide fine pointing stabilization. The initial SOT focal plane instrument package has been selected, and includes a Coordinated Filtergraph Spectrograph capable of extremely high spectral resolution observations in the visible and ultraviolet over small fields, and a Photometric Filtergraph for the highest possible spatial resolution and moderate spectral resolution over larger fields.

**The Solar Soft X-ray Telescope (SSXRT):** The SSXRT is designed to provide a diagnostic capability for the study of the solar corona, and transient events, such as flares, which are predominantly high temperature (ranging from 1.5 to 100 million Kelvin) phenomena. The nature of grazing incidence Wolter I optical systems limits the resolution which can be attained, due to the problems inherent in aligning the curved focal surfaces of the concentrically nested individual mirrors and to the compromises which must be made in on-axis resolution to achieve a greater field of view. The size of the SSXRT mirror (80 centimeter) is determined primarily by the need to achieve sufficient sensitivity to allow high resolution spectroscopy at the scales over which structural changes in flare kernels and thermal gradients in coronal loops (which may be determined by the magnetic field gradients rather than the scale heights) occur. In the chromosphere and lower corona, this scale is several hundred kilometers, and should match the capabilities of the SSXRT (0.5 arc-seconds - 350 kilometers) well.

The problem of coupling high resolution X-ray spectrometers to the highly divergent (i.e., low f number) Wolter I optical system has been a major stumbling block in previous attempts to carry out diagnostic studies of coronal phenomena at high angular resolution. However, this problem can be solved by the use of grazing incidence relay optical (GIRO) systems in the focal plane of the 80 centimeter Wolter mirror. These "GIRO" systems allow not only high resolution spectroscopy, but the development of stigmatic instruments as well, thereby allowing the imaging of extended features at high spectral and angular resolution simultaneously.

**The Solar Extreme Ultraviolet Telescope (SEUVT):** Extreme ultraviolet (~ 500A - 1400A) observations are critical to the study of the upper chromosphere and the lower corona. The use of a large aperture (90 centimeter) normal incidence Gregorian optical system, with special surface treatment to enhance reflectivity at short wavelengths will provide a unique opportunity to extend the ultra high resolution observational capability represented by the SOT, to material as hot as 1.5 million Kelvin by observations in such lines as O VI (1032A), Mg X (625A) and Si XII (499A).

The design goal for the angular resolution of the SEUVT is 0.3 arc-seconds; however, it appears possible that the mirror may ultimately achieve a performance of 0.1 arc-seconds. Such phenomena as propagation of waves in the upper chromosphere and low corona, and the magnetic structure and dynamics of the chromospheric network associated with supergranule boundaries (this network is known to extend to material as hot as 500 thousand Kelvin) can be addressed by the SEUVT.

**The Solar XUV Telescope (SXUVT):** Although very bright features at wavelengths as short as 300A (e.g., HeII 304A) are accessible with normal incidence optics, effective utilization of the large number of unique diagnostic tools provided by lines in the XUV (100A - > 500A) requires the use of a grazing incidence optical system, coupled with both grazing incidence and normal incidence spectrometers. Utilization of the many diagnostic lines accessible in the XUV will permit us to study the thermal structure, density structure, and dynamics of the transition region and the low corona, and to observe the transport of the energy initially contained in high energy particles and the 100 million Kelvin plasma of the flare kernel through the atmosphere. The XUV facility, as envisioned by the ASO Science Definition Team, will utilize a Wolter II grazing incidence optical system with a 40 centimeter aperture, coupled to a variety of focal plane instruments with a unique grazing incidence plane mirror which can accomplish both focal plane instrument selection and image motion.

**The Solar Gamma Ray and Neutron Spectrometer (SGRNS):** The availability of gamma ray burst time profiles, and gamma ray spectra is critical to the ASO program of flare studies; consequently, a gamma ray spectrometer must be an integral part of the ASO capability from the beginning. Simultaneous and detailed temporal and spectral measurements made in this energy band will provide: (i) Time histories of both the acceleration and energy loss process of the energetic electron and ion populations, (ii) Spectral and intensity dependence on flare position on the solar disk, which in turn is controlled by the directivity of the electron and ion population, and (iii) Spectral properties of the emissions, which can provide isotopic abundances.

The proposed Solar Gamma Ray and Neutron Spectrometer design includes X-ray detectors covering the energy range 10-300 keV, a set of high resolution Ge(HP)\* gamma ray spectrometers covering the energy range 0.1 - 10 MeV, a set of high sensitivity scintillator gamma ray spectrometers covering the energy range 0.2 - 10 MeV with moderate energy resolution, and a high energy monitor sensitive to both gamma rays and neutrons greater than 10 MeV.

**The Solar Internal Dynamics Facility (SIDF):** The objectives of the Internal Dynamics Facility are (i) to study the internal structure of the Sun (i.e., density, temperature, composition, magnetic field, and rotation profiles), (ii) to study the solar dynamo and the solar cycle, and (iii) to study large scale circulation and convection in the solar envelope. The scientific program of the SIDF has been discussed in some depth in the report of the SCADM Science Working Group<sup>4</sup>. The major components of the observational program of the SIDF are:

- Precision measurements of the photospheric velocity and magnetic fields to deduce the non-radial oscillations and to study large scale circulation and convection; two different techniques are contemplated, a Fourier Tachometer/Magnetograph and a Magneto-Optical Filter or "Helioseismometer".
- Precision differential radiometry (utilizing an instrument of 15 centimeter aperture) to study large scale convection cells.
- A Radial Seismometer to detect the very low order radial oscillations of the solar diameter, which are thought to be sensitive to such details of the Sun's internal structure as chemical stratification.
- An Integrated Light Spectrometer to study the low order non-radial oscillations, which are sensitive to the deep interior structure of the core.

The arrangement of the SIDF instruments when mounted in the HRSTC is shown in Figure 3, except for the Radial Seismometer, which will be an interferometer, and will require deployment.

#### The Pinhole/Occulter Facility

The Pinhole/Occulter Facility (P/OF) represents a major advance in observational capability in two areas: (i) hard X-ray imaging of the impulsive phase of the flare process, and (ii) the study of the large scale structure and dynamics of the corona and the acceleration of the solar wind. The P/OF consists of a 50 meter boom that separates an occulting mask from an array of detectors and telescopes. The P/OF concept is illustrated in Figure 4. The

\* High Purity Germanium (crystals)

configuration of the occulting mask when deployed is shown in Figure 1. The entire assembly is pointed towards the Sun by a standard IPS-equivalent pointing system. The name "pinhole" derives from the use of the remote occulter to obtain high angular resolution for hard X-radiation, in the same manner that a large pinhole camera would. The imaging actually comes from a coded array of "pinholes" or small apertures; the P/OF can achieve an angular resolution of about 0.4 arc-seconds for the 50 meters separation.

The strawman configuration consists of four separate detector systems: (i) a high resolution hard X-ray imaging system; (ii) a high-sensitivity hard X-ray imager for coronal observations; (iii) a large-aperture white-light coronagraph, and; (iv) an ultraviolet coronagraph. Each of the four instruments

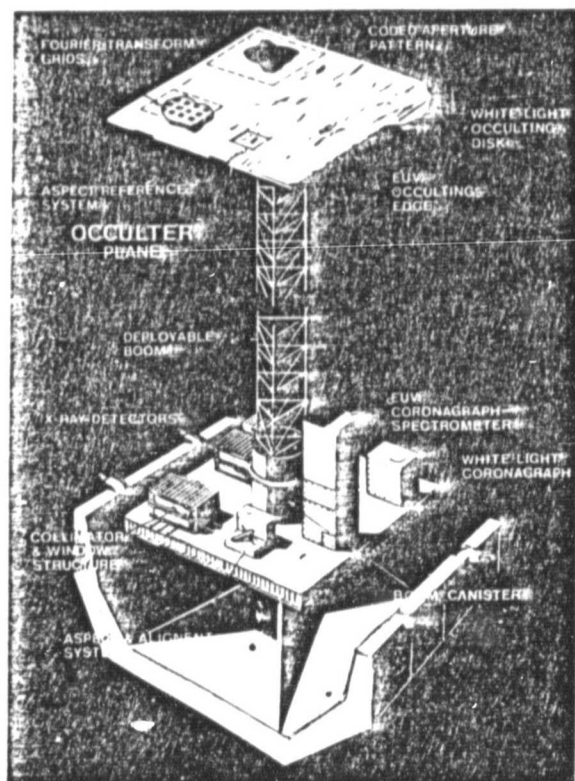


Figure 4. The Pinhole/Occulter Facility mounted on a Space Shuttle pallet.

occupies approximately one quarter of the detector plane, and views the Sun past or through its own sector of the occulter. The coronagraphic observations are in general carried out as with an ordinary externally occulted coronagraph, but with the great advantage of the large-aperture optics made possible by the large shadow cone. Similarly, the X-ray detectors employ very large detector areas to achieve unprecedented sensitivity and time resolution.

The characteristics of the major P/OF components are summarized below.

**Hard X-ray Imaging:** An explosive, non-thermal energy release lies at the core of the solar flare phenomenon. Particles accelerated in the impulsive phase, and in other phases of solar activity, can be studied most directly in the hard X-ray and gamma-ray spectral regions.

The high-energy observations essentially permit us to follow the accelerated particles from their sources, through interactions with the solar atmosphere, to their destinations. From knowledge of the sources we hope to learn about energy storage and release mechanisms; from knowledge of the collisional energy losses we hope to clarify the mechanisms by which a flare converts its explosive energy into relaxed, thermal phenomena such as the hot plasma that emits the soft X-radiation.

Two X-ray imaging systems are planned, a high resolution imager with an angular resolution of 0.4 arc-seconds (total detector area 0.3 square meter) and a high sensitivity imager with a large field of view, and a total detector area of 1.2 square meters. The high resolution imager uses Fourier-Transform Optics; it is a modern derivative of the modulation collimator. The high sensitivity imager is a straight forward coded aperture system, with a single grid on the occulter plane, permitting a large field of view.

**The Ultraviolet Light Coronagraph:** An ultraviolet light coronagraph intended for spectroscopic work must meet very stringent requirements for stray light suppression, spectral resolving power, spatial resolution, and photon collection efficiency. Coronal plasma diagnostics require observations of spectral lines within the 300A - 1700A range and, ultimately, at shorter wavelengths. An appropriate instrument would consist of an external occulter, an internally occulted telescope mirror, a spectrograph and a detection system. External occulting is essential in ultraviolet coronagraphs: otherwise, the inherent surface scatter in mirrors would completely mask all but the innermost coronal regions. An externally occulted coronagraph effectively vignettes the incident coronal light, with the degree of vignetting depending upon the radial height in the corona, thus allowing the faint outer corona to be observed with a much greater effective aperture.

With the P/OF ultraviolet light coronagraph, the acceleration, flow velocity, composition, and dynamical behavior of plasma in the outer corona, in coronal holes, and in the solar wind, can be studied with unprecedented spectral, angular and temporal resolution, and sensitivity.

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**The White Light Coronagraph:** Many of the persistent problems of coronal physics, especially those pertaining to the relationship of the corona to the condition of the photosphere and chromosphere, can be made significantly more accessible by improvements in coronagraph sensitivity and resolution (temporal and spatial), and a lowering of the inner limit of view. The study of the earliest stages of coronal transients, the finest scale structure of the low corona, and the careful mapping of coronal features (holes, streamers, plumes, etc.) to their underlying structures will all be made more feasible by such improvements. These improved capabilities can be achieved by the P/OF because the large occulting assembly at 50 meters distance from the coronagraph objective, allows the use of larger optical systems.

The large relative aperture of the P/OF coronagraph will permit the optimal collection and detection of photons. This will permit improved time resolution and the possibility of narrow band observations, which have heretofore been neglected because of lack of flux, rather than purely wide band (~ 1000Å) observations, enabling emission line measurements to be made as a pressure/temperature diagnostic and line polarization measurements to be made from which the magnetic field can be inferred.

### The Solar High Energy Facility (SHEF)

The Solar High Energy Facility will consist of four complementary instruments which are designed to study the intensity, energy distribution, and directivity of energetic electrons and nucleons from 100 keV to greater than 1000 MeV, by the observations of solar gamma rays and neutrons. The SHEF instruments will represent a large increase in sensitivity, time resolution, energy resolution, and energy range compared to measurements made up to the present, and a significant increase in capability compared to the NRSTC Solar Gamma Ray and Neutron Spectrometer. Among the principal problems which will be addressed by the SHEF are: (i) the definitive identification and detailed study of the particle acceleration mechanism (or mechanisms) operating on the Sun, (ii) the elucidation of the relationship between particle acceleration and the basic flare process, (iii) the elucidation of the relationship between the impulsive flare and the acceleration of the solar cosmic rays, and (iv) the study of elemental and isotopic abundances in the solar atmosphere.

The four SHEF instruments are:

- a moderate sensitivity, high energy resolution array of Ge(HP) spectrometers to study doppler shifts and widths of narrow gamma ray lines and to identify weak lines from low abundance isotopes in the energy range from 0.1 - 10 MeV.
- a high sensitivity, moderate energy resolution array of scintillator

spectrometers to study broad gamma ray lines and to measure the highest time variability in the energy range from 0.1 - 10 MeV.

- a high energy (greater than 10 MeV) gamma ray spectrometer to measure the intensity and time structure of the most energetic tail of the particle distribution via bremsstrahlung and  $\pi^0$  gamma ray emission.
- a sensitive high energy neutron spectrometer to measure the spectral shape of the energetic nucleon spectrum greater than 100 MeV.

The configuration of the SHEF is shown in Figure 1.

### Solar Low Frequency Radio Facility

The solar low frequency radio capability which is envisioned as a part of the ASO initially will be less sophisticated than the other instrument groups described above, since there is at present no organized effort to develop a science facility which operates at radio wavelengths. There is, at present, essentially a gap between the very low frequencies (less than 2 megahertz) with which earth orbiting and deep space probes have identified and tracked bursts of particles ejected from the Sun, and the higher frequencies (greater than 15 megahertz) which can be observed from the ground, and which have been used so successfully as diagnostics for lower coronal conditions.

ASO will provide an opportunity, even with a comparatively modest set of instrumentation, to bridge this gap in frequency and to observe the band of frequencies (1 - 20 megahertz) which arises in the acceleration region of the solar wind. This will allow particle and field information to be traced from the lower levels of the corona out into interplanetary space.

The initial antenna configuration envisioned for the ASO consists of two components: (i) a crossed Dipole Array, approximately 30 meters across and, (ii) Log Periodic Arrays approximately 3 meters long and placed as far apart as possible.

This antenna system should be deployable from the Shuttle with present technology. The SLFRF facility will be capable of resolving the 1-20 megahertz spectrum into 200 channels, and of scanning the spectrum within one second. The configuration of the SLFRF is shown in Figure 1.

## IV. SUMMARY

The Advanced Solar Observatory is one of a number of major long duration space observatories (others include the Space Telescope, to be launched in 1985, and the Advanced X-Ray Astronomy Facility, now scheduled to be started in 1986 and launched in 1989)

which are planned by NASA. Like the other observatories, the ASO is planned to have an active lifetime measured in decades, and will be operated as a national (or international) scientific resource. These major observatories will be operated remotely (i.e. they will be unmanned), but will be serviced in orbit by astronauts operating from the Space Shuttle or Space Station. It is anticipated that major focal plane instruments or entire assemblies (such as the Internal Dynamics Facility) can be removed for repair, or, when appropriate, replaced by more advanced instruments. Thus, the major Space Observatories will function in much the same manner as the major ground based national observatories, such as the Kitt Peak Observatory in Tucson, Arizona, the Sacramento Peak Observatory in Sunspot, New Mexico, and the National Radio Astronomy Observatory in Greenbank, West Virginia.

Because of the great luminosity of the Sun, operations in the Space Shuttle attached "Sortie" or Spacelab mode, which can support observing programs of up to 10 days duration, can be highly productive for solar physics. This is not generally true for other major astronomical facilities (although there are notable exceptions such as the Shuttle Infrared Telescope Facility, SIRTf). Therefore, the ASO can be developed by utilizing a unique evolutionary approach; whereby its major components such as the SOT, the SSXRT, and the P/OF, etc., are first built and deployed as Spacelab Facilities. Furthermore, several Spacelab flights of a developmental version of the ASO, consisting of the HRSTC and P/OF, would not only constitute a major scientific opportunity for solar research, but would also constitute an important engineering test of the ASO design. The Science Definition Team believes that this evolutionary approach will prove to be cost effective, because of the built in (and scientifically valuable) testing which the Shuttle attached operations represent; and will allow scientifically productive and innovative observations (such as will be achieved by the SOT when it commences operation in 1989) to be undertaken sooner than would be possible with a more conventional developmental program.

#### Acknowledgements

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